Deep tillage for improving saline-sodic soils in Idaho

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Only an estimated 10 percent of the world's soils are arable, and only a percentage of these soils are ideal or sufficiently free from adverse physical and chemical conditions to produce optimum crop yields. For this reason, much money and effort have been spent investigating methods of improving the world's so-called problem soils. Only in the last 30 years have the more basic relationships between soil physical conditions and plant growth become of great concern to many people. Now there is an increasing interest in soil and plant mechanics and in discovering how soil physical conditions influence soil-water-plant relationships and overall plant growth.

Over the years, various methods of tilling, deep plowing, or mechanically mixing soils for radically altering and modifying problem soils or improving adverse soil profile conditions have been proposed. These include deep plowing with special disk or moldboard deep plows, 2- or 3-layer (or stage) deep plows, special subsoilers, subsoil plows and rooters, slip plows, and in some cases hauling in soil, sand, gravel, cinders, and organic materials for covering or

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mixing with existing soils (*1, 2, 3, 4, 5, 13, 16, 17, 23, 31, 32, 34*). With the development of larger earthmoving and tillage machinery and more efficient practices, it may be feasible to greatly alter existing soils by deep plowing, mixing, layering, or combining soils. Since our land resources are limited, it may become necessary to improve more marginal and problem soils to feed the world's increasing population.

In the United States deep tillage (subsoiling and subsoil plowing) research has been conducted for a long time. The first work was directed primarily at improving soil physical conditions on soils with inherent adverse genetic properties, such as the claypan (Planosol) soils in the Midwest prairie region. The earlier investigators concluded that subsoiling alone had little effect on crop yields on either the typical well-developed soils or the problem claypan soils. However, lime and lime and phosphate applied in the subsoil during subsoiling operations on some claypan soils increased yields of corn and alfalfa and enhanced the rooting of sweet clovers. Apparently, shallow subsoiling or deep tillage did not increase water infiltration significantly (*12, 17*). More recently, deep tillage investigations have been carried out on claypan and high clay soils in many areas in the U.S. (*11, 12, 15, 22, 28, 30, 33*). Burnett and Hauser (*8*) reviewed the results of many investigations up to 1967.

Methods of improving saline and sodic soils, particularly intensely "solonetz" soils, have been investigated in Russia, Hungary, and eastern Europe for many years. An estimated 25 million hectares (over 60 million acres) of land in eastern Europe and Russia are comprised of solonetz and solonetzic soils (*23*). Extensive reviews of the Russian investigations for improving the saline-sodic solonetz soils in the USSR and descriptions of the diversified methods of improving several "types" of solonetz soils by special deep tillage and deep plowing and combined tillage and amendments were recently published in English (*2, 3, 23, 32*).

The Russian workers stressed "self-amelioration" soil improvement--by deep plowing, trenching, or soil mixing--to mix the naturally occurring gypsum and calcium carbonate from the "lime-rich" substratum layers into the solonetz and surface horizons to supply a "soluble calcium reserve" for replacing the excessive exchangeable sodium. Adequate deep plowing is apparently an effective means of improving many "shallow solonetzic" soils in the USSR, particularly under irrigation. However, the Russian investigators concluded that because of the complexity of solonetzic soils there is no single, universally acceptable method for improving all types of solonetzic soils.

In recent years interest has increased in the U.S. and Canada in soil profile modification, primarily by deep plowing, as a means of improving saline-sodic (solonetz-like) and sodic claypan soils and soils affected by compact, hardpan, or dense clayey subsoil layers. Studies of soil mixing, subsoiling, and deep plowing in combination with gypsum and ferric sulfate were conducted on saline-sodic (slick spot) soils in southern Idaho beginning in 1957 (*24, 25*). The principal results and conclusions obtained from these investigations are summarized later.

Considerable research on similar soils affected by salt and sodium, such as the "solonetzic" soils in western Canada, the "sodic claypan" soils in North and South Dakota, and the "slick spot" soils in Illinois, has been carried out. Several million acres of saline-sodic or solonetzic soils occur in these regions. Studies in western Canada have shown that production on several solonetzic soils was markedly improved by deep plowing, fertilizer, and good soil management under nonirrigated conditions (*7, 9, 10*). Deep plowing experiments on "sodic claypan" or solonetzic soil associations in western North Dakota indicated that mixing or plowing to 16 to 24 inches and adding gypsum and sulfur effectively decreased salinity and exchangeable sodium and increased production (*29*). In Illinois sodic-affected slick spot soils were improved by soil mixing to 3 feet and adding gypsum (*12*). Limited deep plowing tests have been conducted on saline-sodic (claypan) soils on newly irrigated lands in South Dakota by the U.S. Bureau of Reclamation (unpublished report, U.S. Bureau of Reclamation, Huron, South Dakota). More extensive work is underway or being planned on similar soils by South Dakota State University (L. O. Fine, personal communication). Modifying the profile by soil mixing, deep plowing, slip plowing and special subsoiling methods to increase leaching and improve drainage of the highly stratified, saline soils in the Imperial Valley in California is being evaluated near Brawley (*27*).[1]

Soil Reclamation Research in Idaho

Soil improvement studies, including soil mixing, subsoiling, and deep plowing in combination with gypsum and ferric sulfate amendments were carried out from 1957 through 1972 on several salt-affected soil associations in southwestern Idaho. In this region an estimated 150,000 acres of irrigated land are affected by naturally occurring unproductive saline-sodic (slick spot) soils. The unproductive soils occur as random spots intermingled with several related nonsaline soils and may comprise from 15% to more than 50% of the irrigated lands in some fields. The problem soils have distinctive clayey B horizons, sometimes with weakly expressed "solonetz-like" morphology and contain excessive exchangeable sodium and soluble salts. In addition, many of the affected soils and some

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[1] M. Kaddah and L. Hermsmeir. 1973. "Salt Leaching by Ponding and Sprinkling as Affected by Soil Profile Modification." Abstracts, Western Society of Soil Science, paper presented, June 11-14, 1973, Salt Lake City, Utah.

associated soils have compact or cemeted hardpan layers in the lower profile and are resistant to ordinary soil improvement practices. The affected soils are recognizable as areas of poor plant growth by their failure to absorb water adequately when irrigated and by the light color and dispersed appearance of the surface soil (Figure 1). The presence of the troublesome slick spots in otherwise productive land substantially reduces land values and greatly complicates soil and irrigation management.

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Figure 1. Irrigated farmland in southwestern Idaho severely affected by saline-sodic (slick spot) soil. (a) Affected soils appear as light-colored areas of crusted soil in plowed lands in early spring. (b) Poor alfalfa growth on saline-sodic soils. The spots fail to absorb sufficient water to maintain normal plant growth.

Several different and distinct types of saline-sodic-affected soils and complex soil associations occur in southwestern Idaho. Most soils have developed in silty alluvium or mixed loess and alluvium overlying moderately coarse textured calcareous alluvial or lucustrine sediments. Chemical and physical conditions of the slick spot soils and the associated soils may vary considerably within each soil complex. The soils are described and soil improvement research results presented in several reports (*6, 14, 18, 24, 25, 26*). The distinguishing characteristics of the major saline-sodic-affected soils are shown in the profile diagrams of figure 2.

This paper summarizes the results and conclusions from soil improvement studies conducted on the major saline-sodic-affected soils in southwestern Idaho and evidence from long-term observations of the effects of deep tillage and deep plowing operations on operating farms.

Chilcott-Sebree Slick Spot Soils

Chilcott soils are described as Xerollic Durargids. They have silt loam surface horizons with silty clay to clay loam subsoils, grading to coarser textured, calcareous silt loam C horizons with a strongly cemented duripan or silica-lime-cemented hardpan at depths ranging from 17 to 40 inches. The soils are underlain by indurated caliche over unconsolidated granitic sands and gravel or basalt. The Sebree slick-spot soils, classed as Xerollic Nadurargids have similar profile characteristics but very thin silt loam surface horizons with silty clay loam to clay loam subsoils containing 30% to 45% or more exchangeable sodium and moderate levels of soluble salts. The clayey subsoils grade to highly saline, friable silt loam or loam Cca horizons with moderate levels of exchangeable sodium. The soils are underlain by indurated silica-lime-cemented duripans or hardpan layers (Figure 2). Root growth in the untreated Sebree (slick-spot) soils is limited to the upper 8 to 12 inches both because of the lack of penetration of irrigation water, and by the shallow compact or weakly cemented soil layers in the lower profile. Root penetration on the untreated Chilcott soil is restricted by the compact or weakly lime-cemented soil layers at depths of 15 to 17 inches. Because of the low water intake rates and poor water penetration, the soils cannot be wetted adequately even with irrigation lasting from 48 to more than 72 hours.

In the first studies on Sebree slick spot soils, treatments included profile mixing with a backhoe to several depths to simulate deep plowing alone, simulated deep plowing with application of 20 tons of gypsum per acre, simulated deep plowing to 22 inches in combination with deep subsoiling, subsoiling alone (Figure 3), subsoiling with applications of 20 tons of gypsum per acre, and gypsum applications at rates of 20 tons per acre alone. In 1959, when deep plows became available, actual deep

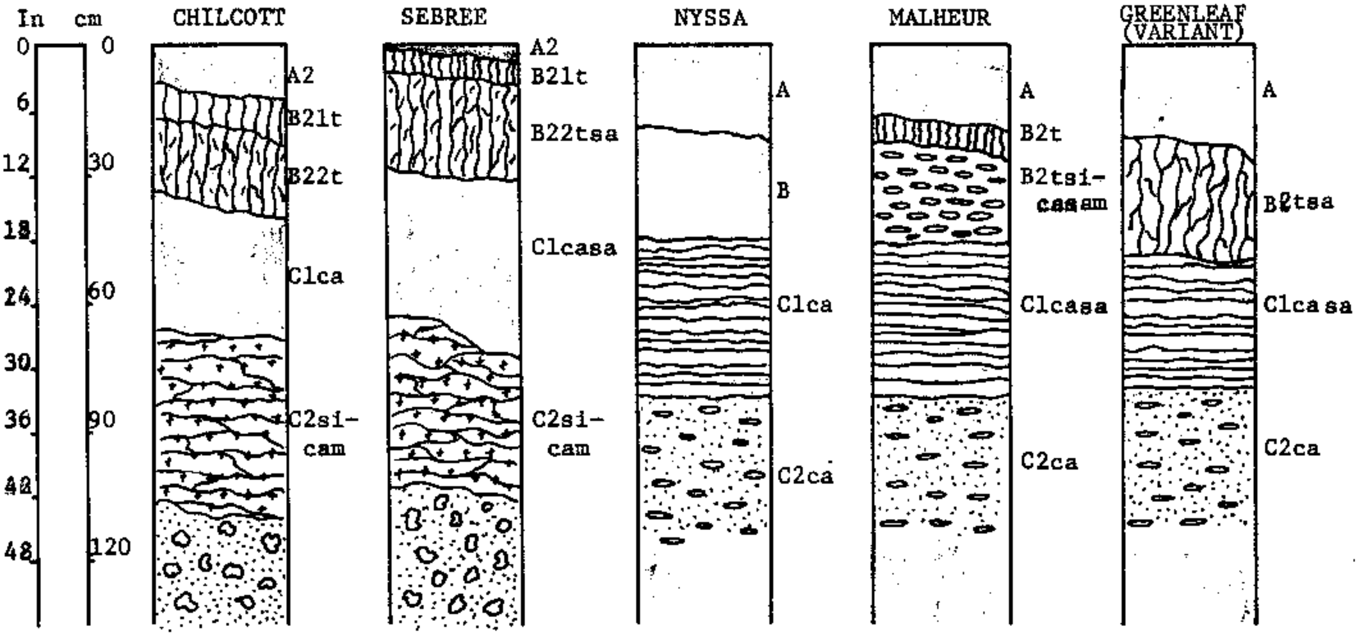

Figure 2. Schematic diagrams of the major saline-sodic and associated soils in southwestern Idaho.

plowing tests with a large moldboard plow, with and without gypsum application, and subsoiling with standard subsoilers and with special subsoilers, with and without gypsum, were evaluated on large field plots.

The sodium-affected Sebree soils were slightly improved by the application of 20 tons of gypsum per acre, but water and root penetration remained very limited. Water intake rates and water penetration were substantially increased initially by subsoiling in combination with gypsum application. However, crop yields were only moderately improved. Subsoiling alone was not beneficial. The soils were improved most economically by moldboard plowing to depths of 30 to 36 inches without applications of

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Figure 3. (a) Tool-bar-mounted subsoiler used in subsoiling tests on Chilcott-Sebree soils. The 48-inch shanks penetrated to about 42 inches but failed to break up the cemented soils below 16 to 18 inches. (b) The limited disruption of the soil profile subsoiled to 42 inches is evident in the excavated plot.

gypsum (Figure 4). The deep plowing treatments greatly increased water intake rates. Water and root penetration on both the Sebree and associated Chilcott soils were more than doubled by plowing 30 inches deep (Figure 5). The soluble salts and exchangeable sodium were reduced to safe levels for most crops within 2 to 3 cropping years with only limited leaching during normal irrigation (Figure 6). The associated Chilcott (nonsaline, nonsodic) soils were also improved by deep plowing, as evidenced by increased crop yields, water intake rate, and depth of water and root penetration. The water intake rates and crop yields have remained satisfactory for more than 10 years following treatment.

All observations and data obtained over a 10- to 12-year period indicate that the Chilcott-Sebree and similar soils can be permanently reclaimed by a single, adequate deep plowing treatment. The deep-plowed soils produced excellent crops of grain, alfalfa, corn, potatoes, and in some cases mint and hops. Deep plowing also has resulted in more homogeneous soil physical conditions and has greatly simplified irrigation and soil management practices. The Chilcott-Sebree soil associations can be deep plowed at 1973 costs of $35 to $45 per acre on a contract basis. About 15,000 to 20,000 acres of the problem soils have been deep plowed. The increased yields of common crops in most areas have repaid the deep plowing costs in 1 to 2 years.

Nyssa-Malheur Soils

The Nyssa-Malheur (slick spot) soil complex association occurs on lower bench land and on the intermediate lake-laid terraces bordering the Snake River and tributaries in southwestern Idaho and adjacent areas in Malheur County, Oregon. The results of earlier soil reclamation studies on these soils have been reported (*6*).

The Nyssa soils, described as Haplaxerollic Durorthids, are calcareous silt loams with little profile development. The soils have loam to fine sandy loam subsoils lying over dense, compact or weakly cemented, laminated, lake-laid sediments at depths from 12 to 38 inches. The Nyssa soils are usually very productive and are considered excellent for irrigation. However, in some locations cemented, nodular hardpan layers or compact silty laminations at shallow depths restrict plant root and water penetration (Figure 2). On the slick-spot-affected lands, the Nyssa soils occur in complexes with inclusions of the Malheur (saline-sodic) soils (tentatively described as a Mollic Nadurargid). The saline-sodic soils in cultivated areas have mixed clayey surface soils with fine-textured clayey subsoils containing high amounts of exchangeable sodium and high concentrations of soluble salts in the lower profile. The Malheur soils in the natural state have silt loam surface horizons 6 to 10 inches thick with 3 to 5 inches of clay loam to silty clay loam subsoils (B21t horizons) containing more than 15% exchangeable sodium. A silica or silica-lime cemented nodular, silty clay loam (duripan) hardpan occurs at 16 to 30 inches (Figure 4). The soils have developed on or over the dense, laminated lake-laid sediments (Figure 2). Water infiltration

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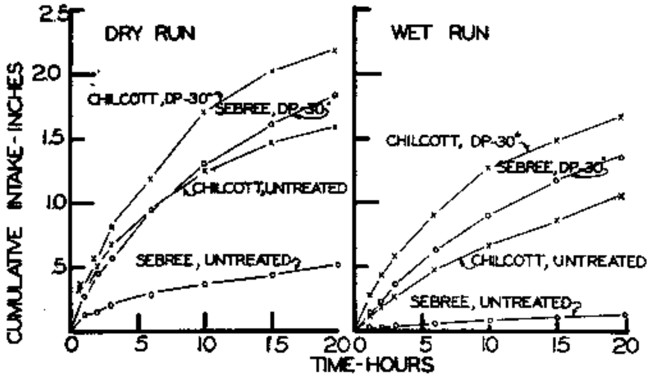
Figure 4. (a) Deep plowing on irrigated cropland affected by spots of saline-sodic (slick spot) soil. Deep plowing mixes the clayey subsoils with the top soil and coarser textured soil from the lower soil horizons and breaks up the cemented soil layers. (b) Hardpan layer in the soil profile of the saline-sodic Malheur soil exposed in furrow on land plowed to 36 inches. Roots of 3-year-old alfalfa plants have not penetrated into the lime- and silica-cemented hardpan that occurs at depths from 14 to 16 inches.



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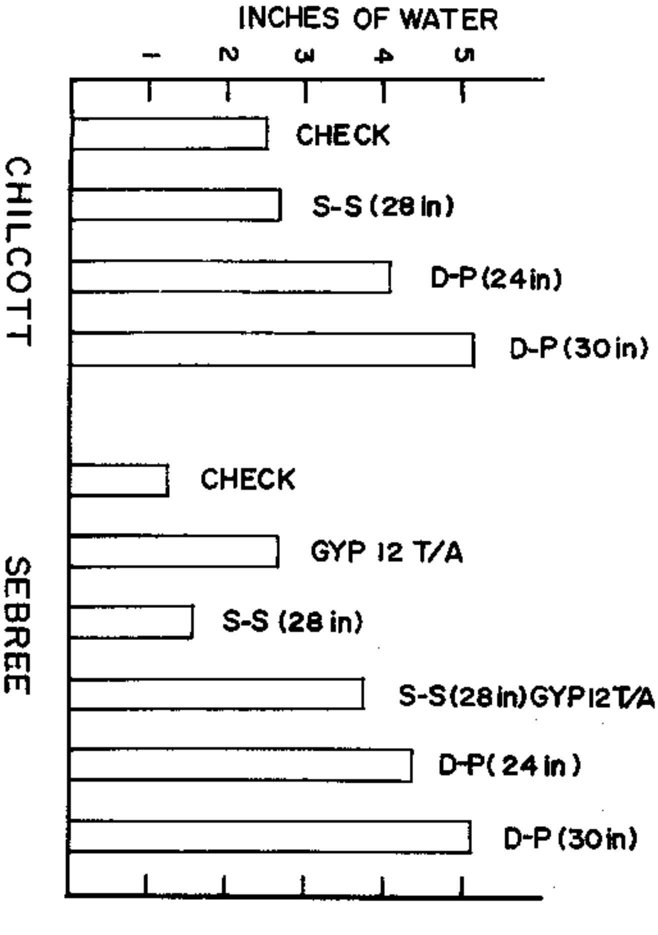

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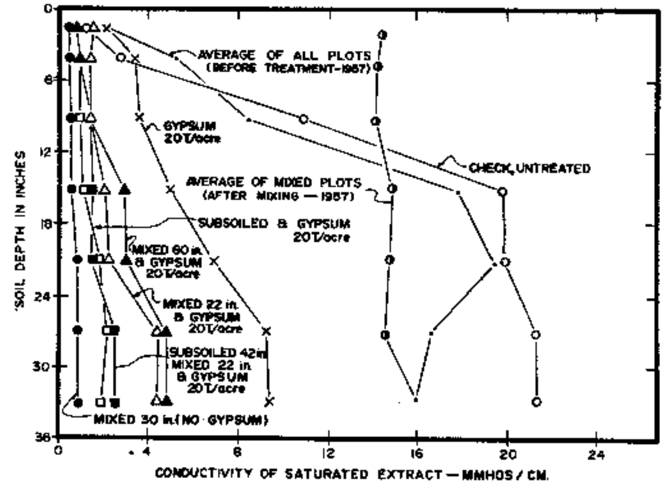
Figure 5. (a) Cumulative water intake as influenced by deep plowing on the Chilcott-Sebree (slick-spot-affected) soils 4 years after treatment. (b) Effects of deep plowing, subsoiling, and gypsum on available water retention of the treated soils.



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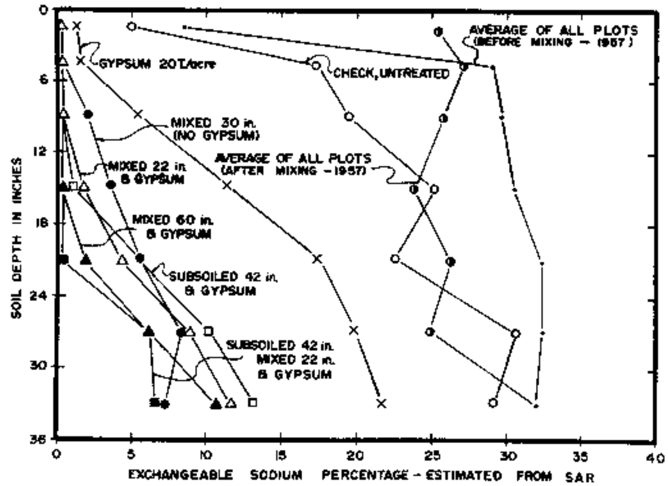

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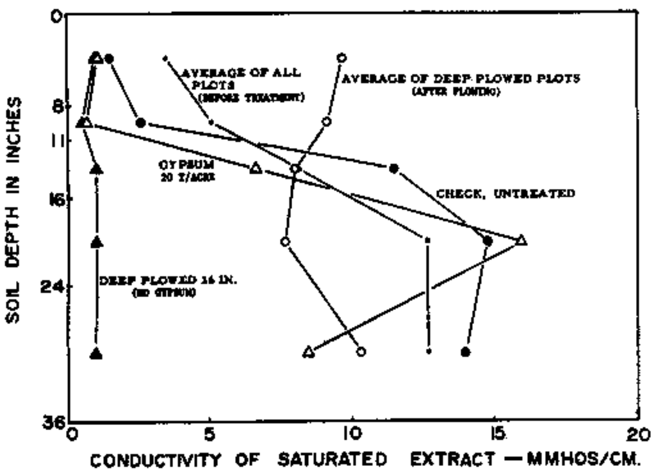
Figure 6. Effect of soil mixing--simulated deep plowing, subsoiling, and gypsum treatments on (a) average soluble salt content (EC_e) and (b) exchangeable sodium percentage (estimated from SAR) with depth in the saline-sodic Sebree soil profile 3 years after treatment. [From Rasmussen et al. (24)].

on the slick spots is extremely limited, and the spots produce only scant growth. As much as 15% to 30% of some areas consist of the unproductive slick spots. Irrigated crop production on the untreated complex soil associations is generally low.

Preliminary soil improvement studies on the Nyssa-Malheur (slick spot) soil associations were begun in the spring of 1959, before deep plowing equipment was available (*25*). The treatments consisted of applications of gypsum at rates of 5, 10, 15, and 20 tons per acre; application of 500 pounds of ferric sulfate per acre; subsoiling to a depth of 30 inches with a special subsoiler having a 10-inch-diameter, fluted, tapered spinner (a molelike device) located behind each subsoil shank designed to increase the shattering of soil material and to partially close the ripper or subsoiler channel; and subsoiling in conjunction with applying the same rates of gypsum and ferric sulfate as above.

Later in 1959 and in 1960, additional soil improvement studies were established on large field plots on two sites on the Nyssa-Malheur soil complex soil association (*25*). The treatments included deep plowing to 36 inches on both



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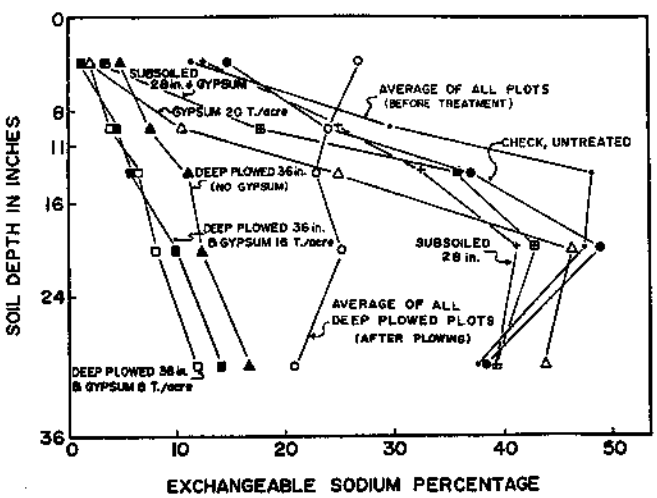

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Figure 7. Effect of deep plowing, subsoiling, and gypsum treatments on (a) the average soluble salt content, expressed as conductivity of the saturated extract (EC_e) in mmhos/cm, and (b) the exchangeable sodium percentage with depth in the profile of the saline-sodic Malheur soil 4 years after treatment.

the slick spot and normal soils, deep plowing 36 inches in conjunction with applying 8 and 16 tons of gypsum per acre on the slick spot soil, subsoiling, and subsoiling plus applying several rates of gypsum on the slick spot and normal soils. The treatments were evaluated by crop responses, by water infiltration measurements, and by changes in exchangeable sodium content, salinity, and other chemical and physical properties of the soil.

The data in figure 7 show that deep plowing with 8 and 16 tons of gypsum added per acre reduced the exchangeable sodium to safe levels throughout the plant root zone within 2 to 3 cropping years. Excessive salts were leached from the active root zone in 1 to 2 crop years. Deep plowing without gypsum appeared to be less effective in reducing the soluble salt concentration and exchangeable sodium percentage (ESP) during the first three cropping years (*25*). This reduced effectiveness has been partially attributed to the smaller amount of water applied to the field cropped to alfalfa for seed production during part of the test period. At the end of the fourth cropping year, the soluble salts and exchangeable sodium of the soils on the deep plowing only treatment were essentially the same as on the deep plowing plus gypsum treatment plots. Malheur soils are nongypsiferous and the available soluble calcium or exchangeable calcium necessary to replace the excessive exchangeable sodium was assumed to come from solution of the moderately high amounts of calcium carbonate or soil lime brought to the surface from the lower soil horizons by deep plowing the soil profile. Gypsum at the rate of 16 to 20 tons per acre markedly decreased the ESP in the 0- to 8-inch depth but had little effect on the ESP (Figure 7) or soluble salt below that depth. The chemical conditions of the untreated slick spot soil remained essentially unchanged during the 4 years the study was conducted.

Other research studies and observations on treated farm lands have shown that deep plowing the highly variable Nyssa-Malheur complex soil association has resulted in a more uniform soil and has simplified both soil and irrigation management. Water infiltration rates, depth of water and root penetration, and plant growth and yields during 10 to 12 years after deep plowing indicate that the sodium-affected Malheur soils have been permanently improved. The yields of several field crops on the treated soils are summarized in table 1. Where the normal, nonsaline Nyssa soils contained cemented high silt laminated soil layers at shallow depths, deep plowing effectively increased the depths of water and root penetration and increased the total water holding capacity. Generally, deep plowing also increased crop yields on the Nyssa soils.

Greenleaf-Malheur (Greenleaf variant) Soil Associations

The Greenleaf silt loam and related soils

Table 1. Summary of average crop yields as influenced by treatments. Nyssa-Malheur Soil Association.[a]

Soil and Treatment	Barley (bu/a)	Wheat (bu/a)	Alfalfa (hay) (t/a)	Corn (silage) (t/a)	Sugarbeets (t/a)
NYSSA Series (Nonsaline Soil)					
Untreated, check	98.6	78.5	5.8	27.2	26.6
Gypsum, 8 t/a	111.1	69.8	-	28.6	23.2
Gypsum, 16 t/a	102.1	76.6	-	29.1	28.8
Deep plowed, 32" (only)	100.7	73.4	6.1	26.5	26.1
Subsoiled, 28" (only)	-	-	5.8	-	-
MALHEUR Series (Slick Spots)					
Untreated, check	23.0	19.9	1.1	15.8	4.6
Nonplowed, Gypsum 8 t/a	41.0	-	-	20.4	-
Nonplowed, Gypsum 16 t/a	22.9	28.9	3.2	25.9	2.1
Deep plowed, 32" (only)	101.4	73.2	5.3	25.8	23.9
Deep plowed, 32" plus Gypsum 8 t/a	103.2	68.8	5.8	25.7	27.7
Deep plowed, 32" plus Gypsum 16 t/a	92.3	68.6	5.0	27.6	25.8
Subsoiled, 28" depth on 42" spacing both ways	30.8	20.9	1.3	14.6	-
Subsoiled, Gypsum 8 t/a	19.1	19.9	-	-	-
Subsoiled, Gypsum 16 t/a	22.9	17.6	1.3	-	-

[a] Average crop yields from several experimental areas and field trials. All treatments were not included in all tests.

occur mainly on old lake-laid sediments on lower terraces in southwestern Idaho and the lower Malheur River Valley in southeastern Oregon. The Greenleaf soils, Xerollic Haplargids, have silt loam surface horizons with silty clay loam or light clay loam subsoils, grading to silt loam or very fine sandy loam lower horizons extending to the high silt, dense, laminated lake-laid sediments. The soils have moderately deep profiles with no restrictions above the laminations. These very productive soils are considered excellent for irrigation; however, water intake rates on the natural Greenleaf (ungraded) soils are low--probably less than 0.2 inch per hour under furrow irrigation. In some areas the Greenleaf soils are associated with considerable areas of the saline-sodic (slick spot) soil as a complex. The low water intake rates and the slick spot conditions create problems in soil and irrigation management. The unproductive soils [once considered similar to the Malheur (saline-sodic) soil described in the section on the Nyssa-Malheur soils] have silt loam surface horizons with clay loam or silty clay loam subsoils overlying the dense, compact or weakly cemented, laminated lake-laid sediments. However, most of the saline-sodic-affected soils do not have a silica- or silica-lime-cemented hardpan, and the soils are now considered to be saline-sodic-affected variants of the Greenleaf soils (Figure 2).

Soil improvement field studies including deep plowing, subsoiling, and gypsum treatments were conducted on areas of Greenleaf (slick spot) affected soils from 1961 to 1964. The results were similar to the results reported for the Nyssa-Malheur slick spot soil associations. All results indicate that the Greenleaf (variant) slick spots were eliminated by deep plowing. Generally, deep plowing also increased crop yields on the associated Greenleaf soils, probably as a result of increased rooting depth and increased water infiltration rates. Crop yields on the deep-plowed Greenleaf (Greenleaf variant) complex are comparable to those reported for the Nyssa-Malheur complex in table 1. Yields on the deep-plowed areas of both the slick spot and Greenleaf soils were as good or better than those on the best areas of the uniform, untreated nonsaline Greenleaf soil.

Unnamed Slick-Spot Soil Associations

Deep plowing and soil modification studies on several unnamed saline-sodic slick-spot-affected soils were conducted from 1966 through 1971. These soils are being considered for inclusion in proposed irrigation development areas in southwestern Idaho. Most soils in this area contain moderately thick, dense clay or clay loam B horizons having excessive exchangeable sodium and soluble salts. Most saline-sodic soils and some associated soils have weakly lime-cemented hardpans or strongly cemented duripans in the lower profiles. Studies were made to determine the effectiveness of deep plowing for improving the irrigability and productivity of the affected saline-sodic soils.

Intensive small plot and large field plot deep plowing studies also were conducted on four or five different sodium-affected soil complexes in desert areas in southwestern Idaho (W. W. Rasmussen, unpublished data, annual reports, Snake River Conservation Research Center, Kimberly, Idaho).

Plowing to depths of 24 to 36 inches improved the irrigability and productivity of salt-affected slick spots soils and the associated nonsaline soils within the several unnamed complex "problem" soil associations. Adequate deep plowing increased water infiltration rates, water and root penetration, and crop yields on all soils. Most of the major salt-affected soil complexes were reclaimed within 3 to 5 years by moderate leaching during usual irrigation and cropping management. At the end of the 6-year experiment, all soils had satisfactory surface textures and reasonably good tilth following adequate mixing. However, some spots of salt-affected soil in one area with thick clay B2 horizons failed to respond adequately to the initial deep plowing. When these soils were remixed with backhoes to simulate deep plowing to slightly greater depths, they were also reclaimed within an additional 1 to 2 years. Based on the results and observations from the deep plowing studies, it appears that most of the approximately 150,000 acres of complex salt-affected soils can be successfully improved for inclusion in potential irrigation development projects in southwestern Idaho.

Determining Depth of Tillage

A question of considerable concern in considering deep tillage, particularly deep plowing or radical soil profile modification, for soil improvement has been the problem of evaluating the long-term effects of soil mixing on saline-sodic and other problem soils. Since the radical mixing of soil profiles is irreversible, great care and judgement must be exercised before soil modification is attempted on an extensive scale. There are few studies on methods and procedures for evaluating mixed soil systems or for determining the need for, and possible beneficial results of, soil profile modification.

In early soil mixing research it was reasoned that after deep plowing and long-term ordinary farm tillage the soils would develop homogeneous layers in the upper profile. Therefore, the final texture and average clay content of the mixed soils could be calculated from the thickness and texture of the various horizons. Initially, the only criteria used to estimate the depth of plowing necessary to chemically reclaim the saline-sodic soils were (a) to mix sufficiently deep to thoroughly disrupt the slowly permeable sodium-affected clayey B horizons and any compact or cemented hardpan layers within the normal root zone, (b) to mix deep enough to bring up enough friable or fragmented coarser textured material from the lower horizons to "dilute" the clay from the B horizons and create a coarser textured soil when mixed homogeneously (through subsequent tillage), and (c) to bring up sufficient calcareous (lime-rich) soil from the substratum layers to supply 4 to 5 percent or more calcium carbonate equivalent material through the profile.

Recently, a laboratory procedure, based on a procedure developed by McNeal (*19*), for predicting the effects of mixed-salt solutions on soil hydraulic conductivity was adapted to assess the long-time effects of soil mixing on problem soils under irrigation. The concepts developed by McNeal (*19*) and McNeal and associates (*20*, *21*) for predicting the permeability decreases due to clay swelling induced by sodium in soils were then used to evaluate the stability of the soil material from the separate horizons and the completely mixed (composited) material from all horizons (simulating soil conditions following deep plowing) for three soils. The data showing the relative hydraulic conductivity (RHC) computed for the soils from the completely mixed soil profiles for the three soils subjected to solutions of very low and low salt concentrations are shown in figure 8. These data show the effects of mixing the "unstable" high clay horizons with increasing amounts of the relatively more stable, coarser textured calcareous soil materials from the lower horizons. The decrease in relative hydraulic conductivity with increasing exchangeable sodium percentage is evident for all soils. The implications and significance of this are discussed in greater detail elsewhere (*26*). The results of the laboratory tests compared favorably with the data from lysimeter and field tests. Further testing and verification of the procedure are needed before the method can be used for evaluating the effects of mixing on other soils.

Tillage Equipment and Methods

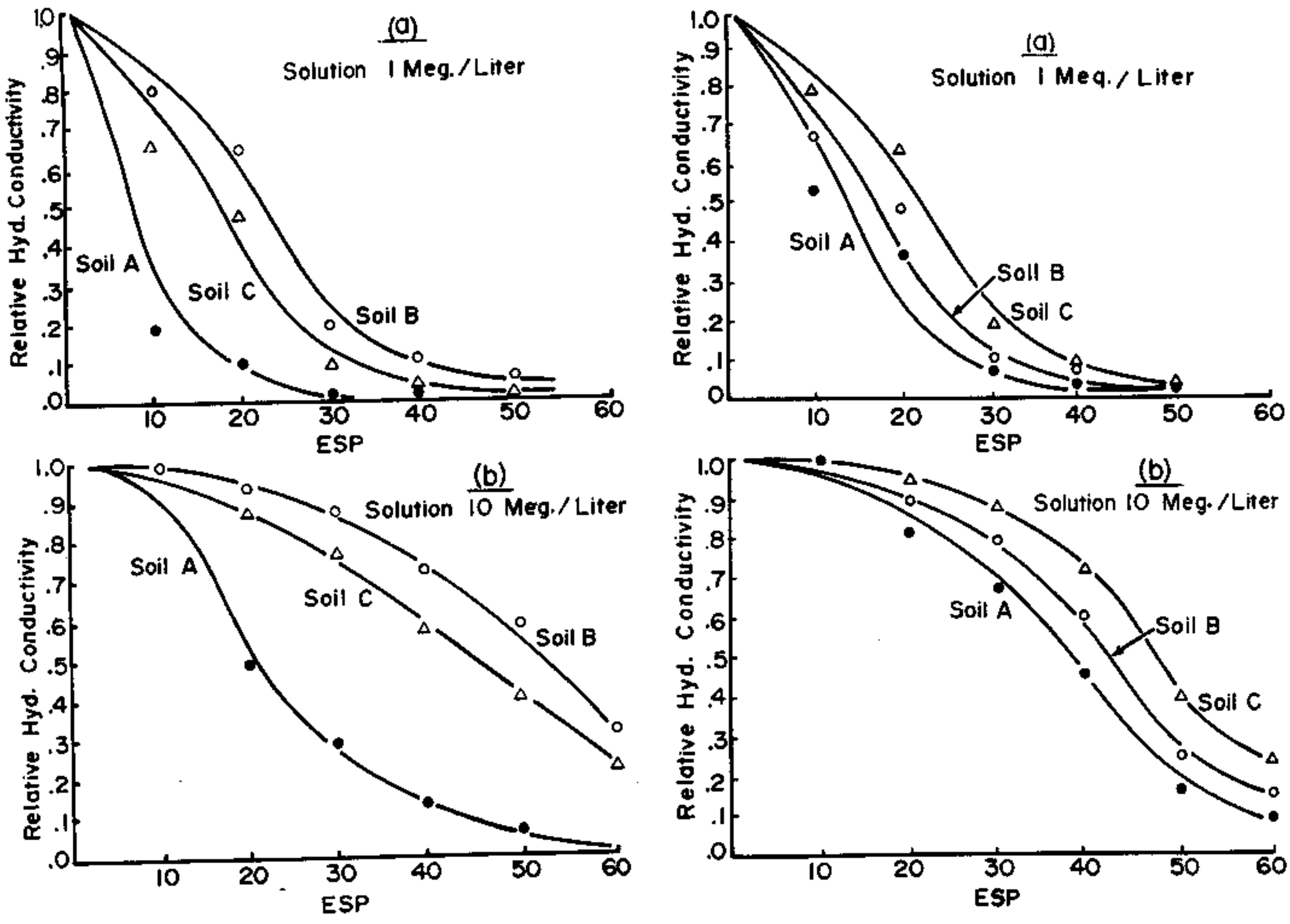
A description of the deep tillage equipment and a brief evaluation of the relative and potential values of the methods tested as means of improving the saline-sodic slick-spot-affected soils in Idaho and Oregon are given in the following sections.

Soil Mixing

Soil mixing with a backhoe to simulate soil profile modification to several depths, both mixing only, and mixing in combination with amendments were tested on several soils. Mixing with a backhoe or by trenching was never considered practical or economical for treating saline-sodic soils on a large scale. However, it has proved to be an effective and economical method for use in preliminary experimental tests. Restricting the irrigation applications, soil sampling, and yield evaluations to small areas provided more homogeneous samples for evaluating treatment effects. Soil mixing by backhoes or trenching can be recommended for preliminary soil profile modification tests when equipment for deep plowing or similar treatments is not available. The results from the soil mixing (simulated deep plowing) treatments compared favorably with the results from actual deep plowing on similar soil areas in large-scale deep plowing tests.

Subsoiling

Deep tillage by subsoiling or ripping had been considered a possible useful treatment for improving the saline-sodic soils in southwestern Idaho for many years, although the effectiveness of the practice was never adequately evaluated. Apparently, the usual method of subsoiling to moderate depths with standard subsoilers or, more commonly, subsoiling using light tillage tools and small tractors was never an effective practice. In the soil improvement studies treatments by subsoiling to several depths and several spacings using heavy-duty subsoilers and large tractors were tried to accomplish different degrees of disrupting or disturbing the subsoil and soil profile and for mixing gypsum into the soil. In most tests neither the compact nor moderately lime-cemented hardpan layers were disrupted to any extent below about 16 to 18 inches. Thus it was concluded that ordinary subsoiling or chiseling as practiced in the area for a number of years apparently has had little effect on soil conditions. In other tests subsoilers with fluted rollers or spinners mounted behind the subsoil shanks were used in an attempt to increase the shattering. The subsoilers with spinner devices disrupted the hardpan when operated within the cemented layers, but they did not mix the soil layers. Even special subsoiling practices failed to mix or alter the surface and clayey subsoil horizons or to break up and disrupt the hardpan



a b

Figure 8. Predicted relative hydraulic conductivity as a function of soil exchangeable sodium percentage (ESP) and solution concentration: (a) hypothetical depth of mixing = 86 cm (34 inches) for soils A and C and 61 cm (24 inches) for soil B; (b) hypothetical depth of mixing = 107 cm (44 inches) for soils A and C and 76 cm (30 inches) for soil B. [From Rasmussen and McNeal (26)].

layers sufficiently to improve the slick-spot-affected areas.

Slip Plowing

Slip plowing is a modification of the deep subsoiling operation. The practice was originally developed in the Imperial and Coachella Valley areas of California (*27*). The slip plow consists of a modified single-shank, heavy-duty subsoiler. A flat steel plate 10 to 12 inches wide and 8 to 10 feet long is attached to the subsoil shank just behind the chisel point and extending back at an angle to near or above the ground surface at the rear of the subsoiler. The purposes of the plate are to increase the disturbance of the soil profile to the depth of tillage, to disrupt any stratified or hardpan layers, and to lift and mix the soil layers in the disturbed area behind the shank. The equipment was developed initially for use in stratified saline soils with clay lenses or slowly permeable layers to increase the leaching of salts and movement of drainage waters into tile and field drains (*27*).[2]

The practice has been used very little in Idaho and has not been fully evaluated on any Idaho soil. In tests by farmers slip plowing to depths of 36 to 42 inches on slick-spot-affected soils with clayey subsoils and strongly cemented hardpan layers apparently did not appreciably improve the soil conditions. The results appeared to be similar to those from subsoiling only, and any beneficial effects persisted for only one year. Costs of heavy slip plowing ranged from $40 to $60 per acre. Observations by Soil Conservation Service personnel and others indicate that slip plowing will not permanently improve the saline-sodic soils or associated soils having dense clayey subsoil layers.

Deep Plowing

Three types of commercially available deep plows were tested in southwestern Idaho. In the first trials a three-bottom disk plow equipped with three 44-inch disks and weighing approximately 13,000 pounds was used. In no tests did the plow penetrate more than about 16 to 18 inches into either normal or saline-sodic-affected soils.

A smaller heavy-duty, two-way deep plow, equipped with three 16-inch bottoms mounted on 28-inch standards, was used to a limited extent on the slick-spot-affected soils in some areas. This plow penetrated about 24 inches deep in most areas. The small 16-inch bottoms operating at this depth substantially disrupted the compact and moderately cemented hardpan and substratum layers, but they failed to sufficiently mix or invert the surface soils. Water intake rates were not improved because the clay subsoil horizons were not mixed and the undisturbed sodium clay remained near the surface of the treated soils. The deep plowing failed to bring up sufficient amounts of the coarse-textured calcareous layers for mixing throughout the profile.

Two sizes of the heavy-duty, single-bottom, one-way moldboard deep plows (manufactured by the Post Plow Co.[3]) have been successfully used in this area. The moldboard plows penetrate well into the hardened lime and lime-silica-cemented hardpan and also the caliche layers common in many soils. The 4-foot model operating at depths of 30 to 36 inches did not invert the soil completely but in most cases thoroughly disrupted the hardpan layers and partially inverted and mixed the clay B horizons and surface layers with the finely divided calcareous coarser textured soil from the friable C horizons. Frequently, relatively large aggregates of the prismatic sodic B2 horizon and chunks from the hardpan layers persisted for sometime following plowing. However, the mixed soils were readily penetrated by plant roots and irrigation water. Subsequent tillage with farm-type plows readily mixed the surface of the deep-plowed soils and resulted in homogeneous mixtures to at least 12 to 14 inches deep.

A 3-foot moldboard plow was used on some test sites and on operating farms. When operated with sufficient power, this plow tends to operate more normally than the 4-foot plow at the 30- to 36-inch depths. When operated at 4 to 5 miles per hour, it inverts the soil to a greater extent and more adequately mixes the upper soil horizon. However, the 3-foot and 4-foot plows have similar power requirements. The 3-foot plow requires power equivalent to two 250-horsepower tractors to adequately plow and mix the slick-spot-affected soils.

One 6-foot moldboard plow has been used to a limited extent in the area. This plow, when operated using two 325-horsepower tractors, penetrated 42 to 48 inches deep and adequately mixed the slick-spot and hardpan-affected soils. The 6-foot plow operated well under most soil conditions.

Very rugged and strong plows are necessary for deep plowing the slick-spot-and hardpan-affected soils containing dense clayey B horizons, lime-cemented hardpan and strongly cemented lime-silica duripan horizons, and abrasive, indurated caliche layers. The plow shares and wearing points on the plow bottoms and moldboards must be protected by hard surfacing. Often the plow shares must be changed every 3 to 4 hours. The strain and wear on plow bottoms and the entire plow frame are extreme. The wear on equipment and the high draft power required to plow such soils to

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2 Ibid.

3 Company names are included for the benefit of the reader and do not imply endorsement of the product listed by the U.S. Department of Agriculture.

adequate depths add substantially to the cost of deep plowing. Satisfactory plowing with a 4-foot moldboard plow has been done with a single 300- to 350-horsepower crawler-type tractor. Frequently, however, the single tractors do not have sufficient weight or traction to operate the plows at constant depths. The deep plows operate more efficiently and effectively when operated at speeds of 3 to 4 miles per hour. Generally, plowing has been more satisfactory when two larger 250-horsepower crawler tractors were used.

Summary and Conclusions

The soil improvement and deep tillage research conducted on the saline-sodic (slick spot) soils in southwestern Idaho has demonstrated that the soils can be improved most effectively and economically by adequate deep plowing. The salt-affected soils in all complexes were chemically reclaimed under field irrigation within 2 to 4 years by deep plowing 24 to 36 inches without adding gypsum or other amendments. Both the chemical and physical properties of the sodium-affected soils and the physical conditions of most nonsaline associated soils were improved by adequate deep plowing. Water infiltration rates and depths of water and root penetration were greatly increased and have remained at satisfactory levels for more than 12 years. The problem soils were slightly improved by large applications of gypsum and by subsoiling with gypsum, but water and root penetration remained limited. Subsoiling alone was not beneficial. Slip plowing apparently has improved drainage and leaching on stratified soils in some areas, but it has had only a transient and limited effect on the slick spot soils. The devices have not been fully evaluated on Idaho soils.

At the present time, deep plowing with large moldboard deep plows appears to be the only practical and economical means of significantly altering and improving the adverse soil conditions on a large scale. The mixed soils are more uniform, which has simplified irrigation and soil management. Soil textures and soil tilth appear to be satisfactory for the production of most crops. Crop yields on irrigated lands seriously affected by the saline-sodic spots have been increased 50% to more than 100% by deep plowing. All evidence and observations 10 to 15 years after treatment indicate that the soils have been permanently improved by a single adequate deep plowing treatment. In 1973, deep plowing cost from \$35 to \$45 per acre. Increased yields of common crops can repay the plowing costs within 1 to 2 years. Deep plowing has been readily accepted by landowners. About 25,000 acres of slick-spot-affected lands in southwestern Idaho have been deep plowed.

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